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U.S. NAVAL AIR MATERIAL CENTER

PHILADELPHIA, PENNSYLVANIA

AERONAUTICAL MATERIALS LABORATORY

REPORT NO. NAMC-AML-1319 DATE 28 November 1961

INVESTIGATION OF SPOT WELDING CHARACTERISTICS OF TITANIUM ALLOYS

PROBLEM ASSIGNMENT NO. C 10 RMA 23-1 UNDER BUREAU OF NAVAL WEAPONS WEPTASK RRMA 02 018/200 1/R007 05 001

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Prepared by: Edward F. Deesing
Edward F. Deesing — Project Engineer

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ABSTRACT

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I. INTRODUCTION

Before a new material can be properly used to the fullest advantage, fabrication techniques must be developed which will not introduce deleterious properties into the material. Of all the conventional joining techniques available, resistance welding offers a most convenient and practical means for fabrication.

With the introduction of titanium alloys as potential aircraft and missile materials, the need to develop joining techniques to fabricate titanium alloys prompted the Bureau of Naval Weapons to authorize a program to determine the resistance welding characteristics of titanium alloys. In the first two phases of this program, reported as Parts 1 and 2 of the subject problem assignment, the effects of resistance welding parameters were determined and welding schedules were developed which would provide optimum joint efficiency for three alloys of titanium which were immediately available.

In this phase of the program, the mechanical properties of resistance welded joints in titanium alloys at room and elevated temperatures and the effect of joint design on the mechanical properties are reported.

This report completes the work originally outlined for the titanium alloys, 4Al-3Mo-1V, 6Al-4V and 16V-2.5Al. Subsequent reports will be issued as the work is completed on the titanium alloys 8Al-1Mo-1V, 7Al-12Zr, 13V-11Cr-4Al, and 5Al-5Zr-5SN.

II. SUMMARY OF RESULTS

1. Fatigue tests of multiple spot welded joints in the three titanium alloys indicated that the alpha-beta alloys, 4Al-3Mo-1V and 6Al-4V, had higher fatigue strength than the all-beta alloy, 16V-2.5Al. The fatigue strength of the 4Al-3Mo-1V-Ti alloy was approximately 10% of the static shear strength of the joint. The fatigue strength of 6Al-4V-Ti and 16V-2.5Al-Ti alloys were both about 8% of the static shear strength.

2. No improvement in fatigue strength was realized by post forging of the weld nuggets during the weld cycle. The post forging of the weld nuggets in the 4Al-3Mo-1V-Ti and 6Al-4V-Ti alloy materials actually resulted in a lower fatigue strength. The aforementioned alloys are both alpha-beta alloys.

3. A uniform decrease in spot weld shear strength resulted as the temperature of testing was increased. The shear strength of single spot welds in the 4Al-3Mo-1V-Ti alloy decreased from 1880 lbs. at 200°F to 1180 lbs. at 1000°F. The rate at which the shear strength decreased was about 500 lbs. for each 100°F rise in test temperature.

4. Room temperature strength of spot welds in the 4Al-3Mo-1V-Ti alloy was retained after exposure at 600°F for 250 hrs. After exposure at 600°F for 500 hrs. a reduction in strength occurred but continued exposure at 600°F for 1000 hrs. resulted in no further decrease in strength. At temperatures above 600°F, the strength of spot welds in the 4Al-3Mo-1V-Ti alloy decreased after 1 hr. exposure time and continued to decrease as exposure time was increased.

5. At an exposure temperature of 900°F, the strength of the spot welds decreased for times up to 100 hrs. After an exposure time of 1000 hrs. at 900°F, the strength increased sharply to the unexposed strength level.

6. Overlap distance down to 3/8" on .060" gage material resulted in nugget pullout type failures with no reduction in the shear strength. At a 1/4" overlap distance expulsion of metal occurred and sheet tearing was the mode of failure during tensile testing.

7. Very little change in nugget size or configuration was noted even when the edges of consecutive spot welds coincided.

III. CONCLUSIONS

The fatigue strength of multiple spot welded joints in the three titanium alloys, 4Al-3Mo-1V-Ti, 6Al-4V-Ti, and 16V-2.5Al-Ti, was 8-10% of the static strength of the joint. No improvement in fatigue strength was obtained by post forging of the weld nuggets. The post forge pressure may have been insufficient to produce the cold work necessary to bring about this improvement.

The shear strength of spot welded 4Al-3Mo-1V-Ti alloy material at elevated temperatures decreases at a regular rate equal to about 500 lbs./spot weld for each 100°F rise in temperature.

The 4Al-3Mo-1V-Ti alloy spot welded and exposed to elevated temperature is thermally stable at 600°F for exposure times up to 250 hrs. For longer periods of exposure at 600°F and at higher temperatures for exposure times as short as one hour, the strength of the spot welded joint is reduced.

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1. Material and Welding Procedure

Three alloys of titanium in three gage thicknesses were supplied by the Department of Defense Titanium Sheet Rolling Program. The materials, "as-received", were in the solution treated and aged condition and were mill pickled. All resistance welding was performed on "as-received" material following degreasing with trichloroethylene. Chemical analysis and mechanical properties of these materials were reported in Part 2 of this problem assignment.

The resistance welding equipment used in preparing all spot welds was a Sciaky Tri-phase Welder, Model PMCO-4ST rated at 150 KVA. RWMA Class 2 electrodes having a 5/8" diameter and a 4" dome radius were found to be satisfactory for spot welding of titanium alloys.

Weld schedules developed in Part 2 of the subject problem assignment, were used throughout this final phase of the project. One exception was the use of variable pressure to obtain the post forge of the spot weld nuggets for the fatigue specimens. Listed below are the actual weld schedules which were used.

Alloy	Gage	% Weld Phase Shift	Weld Time	Constant Electrode Force	Post Forge Pressure
4Al-3Mo-1V	.060 (in.)	50 (%)	4(~)	1200 (lbs.)	1000 – 4400 (lbs.)
	.040	40	4	1000	
6Al-4V	.060	45	5	1200	1000 – 4400
	.040	35	4	1000	
16V-2.5Al	.060	45	5	1200	1000 – 4400
	.040	35	4	1000	

2. Fatigue Tests of Multiple Spot Welded Specimens

Twenty multiple spot welded specimens of each of three titanium alloys were prepared using constant weld pressure in the weld schedule for ten specimens and using variable pressure with a post forge pressure equal to four times the weld pressure in the weld schedule for the remaining ten specimens. The type of specimen used in these tests is shown in Plate 1. A Krouse Direct Stress Fatigue Machine of 15,000 lbs. capacity was used in performing these tests. Specimens were subjected to 100 cycles of stress per minute and the load applied to the specimens during each cycle varied between a pre-load value of 25% of a pre-determined maximum and maximum, for a stress ratio of 0.25. Results of the fatigue tests are shown in Tables 1 and 2 and displayed graphically in Plates 2 and 3.

Using 10^7 cycles as the criterion for titanium alloys, the alpha-beta alloy, 4Al-3Mo-1V was found to have the highest fatigue strength; the all-beta titanium alloy, 16V-2.5Al, had the lowest fatigue strength with the alpha-beta alloy 6Al-4V being intermediate between the two. Triplicate specimens of each alloy material similar to the fatigue specimens were subjected to a static-tensile test for comparative purposes. Results of the static tests are given in Table 3. A comparison of the fatigue strength to static tensile strength is given in Table 4. For all three alloys, the fatigue strength was 8-10% of the static tensile strength of the material. The ratio of fatigue strength to tensile strength was unchanged by the post forging of the weld nuggets in both the all-beta 16V-2.5Al and alpha-beta 6Al-4V. The fatigue strength of the 4Al-3Mo-1V alloy was considerably reduced in the post forged condition. These low values are believed to be due to weld cracking induced when the weld nuggets were post forged.

A comparison of shear strength of single spot specimens with the shear strength of individual spot welds in the multiple spot specimens shown in Table 5 indicated a significantly lower strength level per spot weld in the multiple spot weld specimens. For the three alloys, the shear strength per spot weld was approximately 400 lbs. lower.

3. Short Time Elevated Temperature Tests

Elevated temperature tests were conducted on one of the three alloys, 4Al-3Mo-1V-Ti, in a gage thickness of .040". The specimen consisted of two coupons 1" x 10" joined by a single spot weld using an overlap of 1". Specimens were mounted in the clamping fixture of a tensile testing machine and were heated to various temperatures in a split type cylindrical resistance furnace mounted around the specimen. After allowing the temperature of the specimen to reach equilibrium, the specimens were stressed in tension. All failures occurred by pullout of the weld nugget. The results of the tests are given in Table 6 and are presented graphically in Plate 4. The shear strength of the spot welded joints is shown to decrease at a uniform rate as the temperature of testing is increased. The rate of decrease is about 500 lbs./spot weld for each 100°F increase in temperature.

4. Thermal Stability Tests

Triplicate single spot specimens of the 4Al-3Mo-1V-Ti alloy were exposed at various temperatures for extended periods of time. Tensile tests of these specimens (1" x 4" coupons spot welded with a 1" overlap) were then conducted at room temperature. Failure of all specimens occurred by pullout of the weld nugget accompanied by a sharp cracking sound indicating a brittle type failure. The results of the tests are given in Table 7 and shown graphically in Plate 5.

After exposure at 600°F for 500 hrs., the strength of the spot welded joints was observed to drop off abruptly but no further decrease occurred

after 1000 hrs. exposure. Exposure at temperatures of 700°F and 800°F resulted in a gradual decrease in shear strength as the time of exposure was increased. The behavior of the spot welded material after exposure at 900°F was unusual in that after showing a uniform decrease in shear strength after 100 hrs. exposure, the shear strength increased sharply after being exposed for 1000 hrs. The shear strength after this 1000 hr. exposure at 900°F was the same as the unexposed spot welded material. Confirmation of these results was made by repeating the exposure and retesting. This anomalous behavior can only be theorized at this time as being due to a time dependent hardening process occurring at elevated temperatures. The chief hardening process occurring in alloys of this type is known as beta prime embrittlement. Ordering of the crystal structure was discounted as a possible mode of hardening due to the low percentage of alpha stabilizer present in the 4Al-3Mo-1V-Ti alloy. Ordering has been detected in those alpha-beta alloys containing more than 8% aluminum and small quantities of beta stabilizers. Additional work in this direction is deemed necessary to fully explain this erratic reponse.

5. Overlap Distance and Spot Weld Spacing

For purposes of design, the minimum overlap distant and spot spacing were determined. Several specimens were prepared using various overlap distances with the spot weld made at the mid point of the overlap distance. Satisfactory welds were prepared up to the point where the edge of the weld nugget coincided with the edge of the specimen although expulsion of metal occurred at this overlap distance.

Spot welds were made on a double strip of material with the spot welds located at various spacings in increments of 1/4" to 1" spacing. Below 1" spacing 1/8" increments were used until the welds overlapped. Cross-sectioning of the weld nuggets revealed no significant change in size or configuration of weld nuggets located 1/8" apart. The weld nuggest which overlapped were not significantly dissimilar.

RESULTS OF FATIGUE TESTS OF MULTIPLE SPOT WELDED JOINTS IN TITANIUM ALLOY SHEET MATERIALS
(Gage = .060")(Constant Pressure)

Load (lbs)	Cycles to Failure: 16V-2.5Al Alloy	Cycles to Failure: 6Al-4V Alloy	Cycles to Failure: 4Al-3Mo-1V Alloy
4000	56,600	73,300	46,000
3500	-----	87,200	93,300
3000	104,000	168,200	152,000
2500	127,500	293,500	305,800
2200	-----	446,300	503,700
2000	247,800	837,400	5,990,700
1900	-----	-----	8,158,900*
1950	-----	-----	8,443,500*
1800	-----	981,500	-----
1700	507,100	-----	-----
1600	-----	2,207,800	-----
1500	644,200	3,157,500	-----
1400	-----	9,000,000*	-----
1300	846,800	-----	-----
1200	1,028,400	-----	-----
1100	1,145,000	-----	-----
1000	10,000,000*	-----	-----
Fatigue strength at 8,000,000 cycles	1000 lbs.	1400 lbs.	1950 lbs.

Note: *No failure.

TABLE 1

RESULTS OF FATIGUE TESTS OF MULTIPLE SPOT WELDED JOINTS IN TITANIUM ALLOY SHEET MATERIALS (GAGE .060")
(POST FORGED DURING WELD CYCLE)

Load (lbs)	Cycles to Failure: 16V-2.5Al Alloy	6Al-4V Alloy	4Al-3Mo-1V Alloy
4000	57,600	44,900	37,600
3500	94,200	-----	-----
3000	121,200	264,800	164,500
2500	265,700	327,900	256,000
2000	481,000	562,200	356,200
1700	918,400	923,200	799,400
1500	1,065,100	1,282,300	2,555,700
1300	3,602,800	5,913,800	1,655,500
1200	1,925,200	1,048,600	-----
1200	-----	1,868,800	-----
1200	-----	4,362,000	-----
1100	5,693,700	2,131,800	6,098,400
1100	-----	1,776,500	-----
1000	5,203,500	-----	8,000,000*
Fatigue strength at $8x10^6$ cycles	1100 lbs.*	1100 lbs.*	1000 lbs.

Note: *Extrapolated.

TABLE 2

RESULTS OF STATIC TENSILE TESTS OF MULTIPLE SPOT WELDED JOINTS IN TITANIUM ALLOY SHEET MATERIALS (GAGE = .060")

Alloy		Ultimate Tensile Load (lbs) Constant Pressure	Avg/Spot		Post Forged	Avg/Spot
16V-2.5Al		11,900	1700		11,900	1700
		11,700	1671		11,700	1671
		11,600	1657		12,000	1714
	Avg.	11,733		Avg.	11,866	
6Al-4V		15,000	2143		16,400	2343
		16,500	2357		17,500	2500
		18,250	2607		17,250	2464
	Avg.	16,583		Avg.	17,050	
4Al-3Mo-1V		19,800	2835		19,700	2814
		18,700	2671		19,250	2750
		18,750	2678		19,300	2757
	Avg.	19,100		Avg.	19,416	

TABLE 3

COMPARISON OF FATIGUE STRENGTH TO STATIC STRENGTH OF MULTIPLE SPOT WELDED JOINTS IN TITANIUM ALLOY SHEET MATERIALS (Gage.= .060")

Material	Static Tensile Strength		Fatigue Strength		% Static Strength	
	Constant Pressure*	Post-Forged*	Constant Pressure	Post-Forged	Constant Pressure	Post-Forged
4 Al-3Mo-1V	19100	19416	1950	1000	10.2	5.1
6Al-4V	16583	17050	1400	1100	8.4	8.2
16V-2.5Al	11733	11866	1000	1100	8.5	8.5

NOTE: *Refers to application of pressure during the welding cycle.

TABLE 4

COMPARISON OF SHEAR STRENGTH OF SINGLE SPOT WELD SPECIMENS TO SHEAR STRENGTH PER SPOT WELD OF MULTIPLE SPOT WELD SPECIMENS

Alloy	Condition	Static Load/ Single Spot Coupon	Static Load/ Spot/Panel
4Al-3Mo-1V .060/.060-1"W Soln. Treat-Aged	As Welded Constant Pressure	3410	2728
	Post-Forged After Weld	3370	2774
6Al-4V .060/.060-1"W Soln. Treat-Aged	As Welded Constant Pressure	2830	2369
	Post-Forged After Weld	2800	2436
16V-2.5Al .060/.060-1"W Soln. Treat-Aged	As Welded Constant Pressure	2006	1676
	Post-Forged After Weld	1957	1662

TABLE 5

RESULTS OF SHORT-TIME ELEVATED TEMPERATURE TENSILE-SHEAR TESTS OF SINGLE SPOT WELDS IN Ti-4Al-3Mo-1V ALLOY SHEET MATERIAL (GAGE = .040")

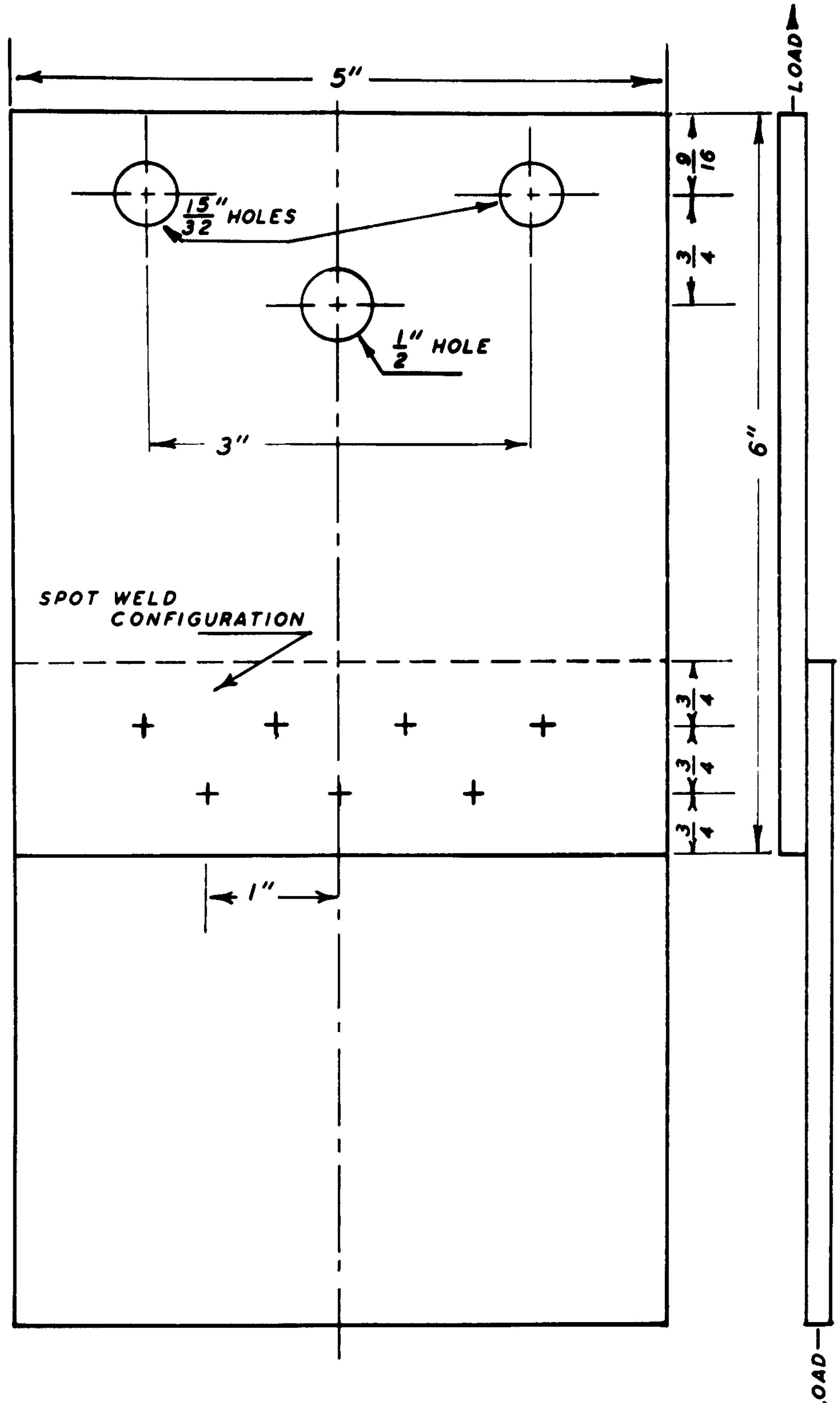
Test Temperature (°F)	Tensile-Shear Load (lbs.)	Avg. Load
200	1842	
	1850	1883
	1958	
300	1850	
	1765	1813
	1824	
400	1748	
	1740	1728
	1696	
600	1508	
	1516	1519
	1532	
800	1280	
	1344	1324
	1350	
1000	1200	
	1120	1183
	1230	
1200	940	
	960	955
	964	

TABLE 6

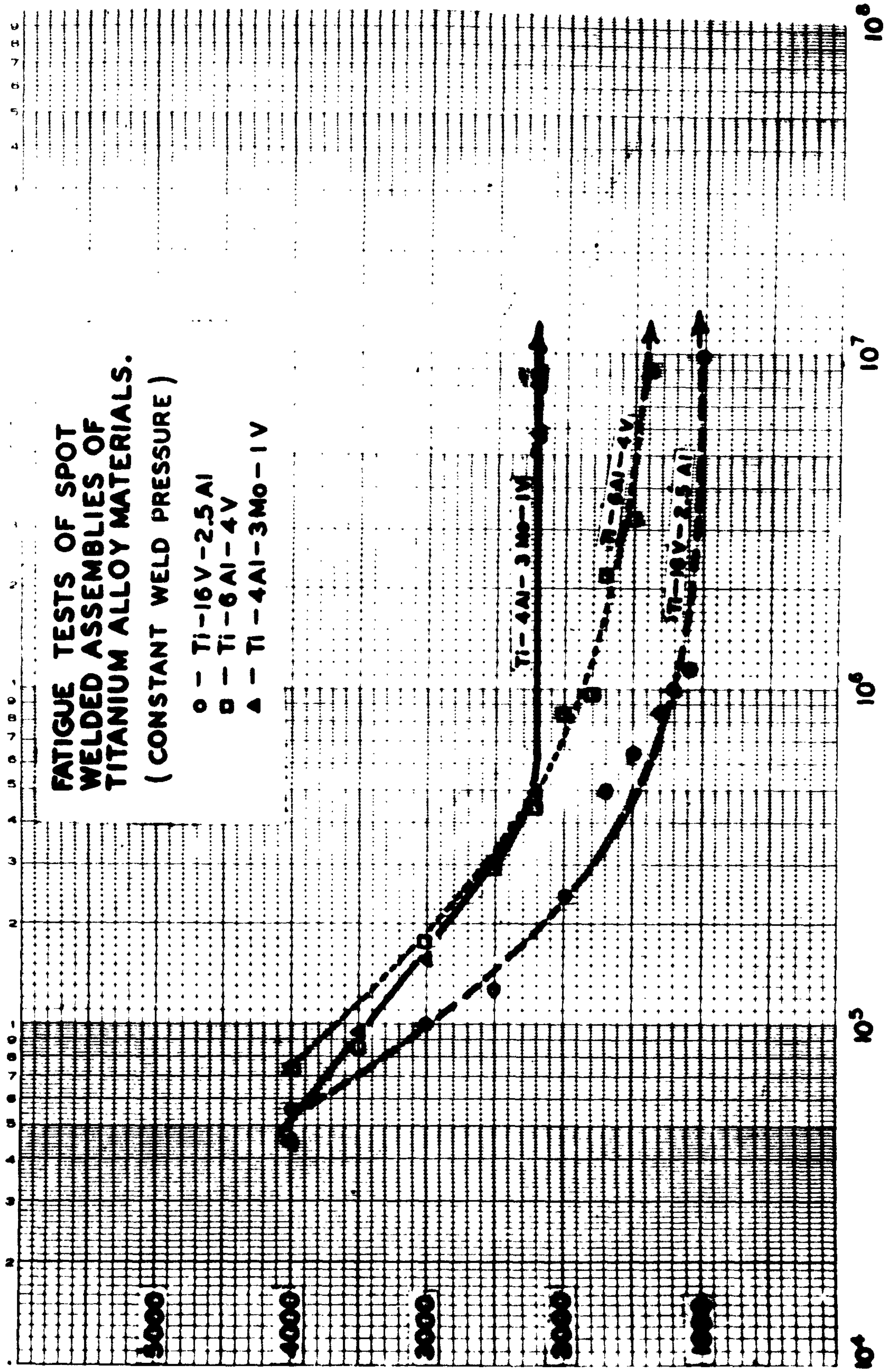
RESULTS OF THERMAL STABILITY TESTS OF SPOT WELDS IN Ti-4Al-3Mo-1V ALLOY SHEET MATERIAL (GAGE - .040")

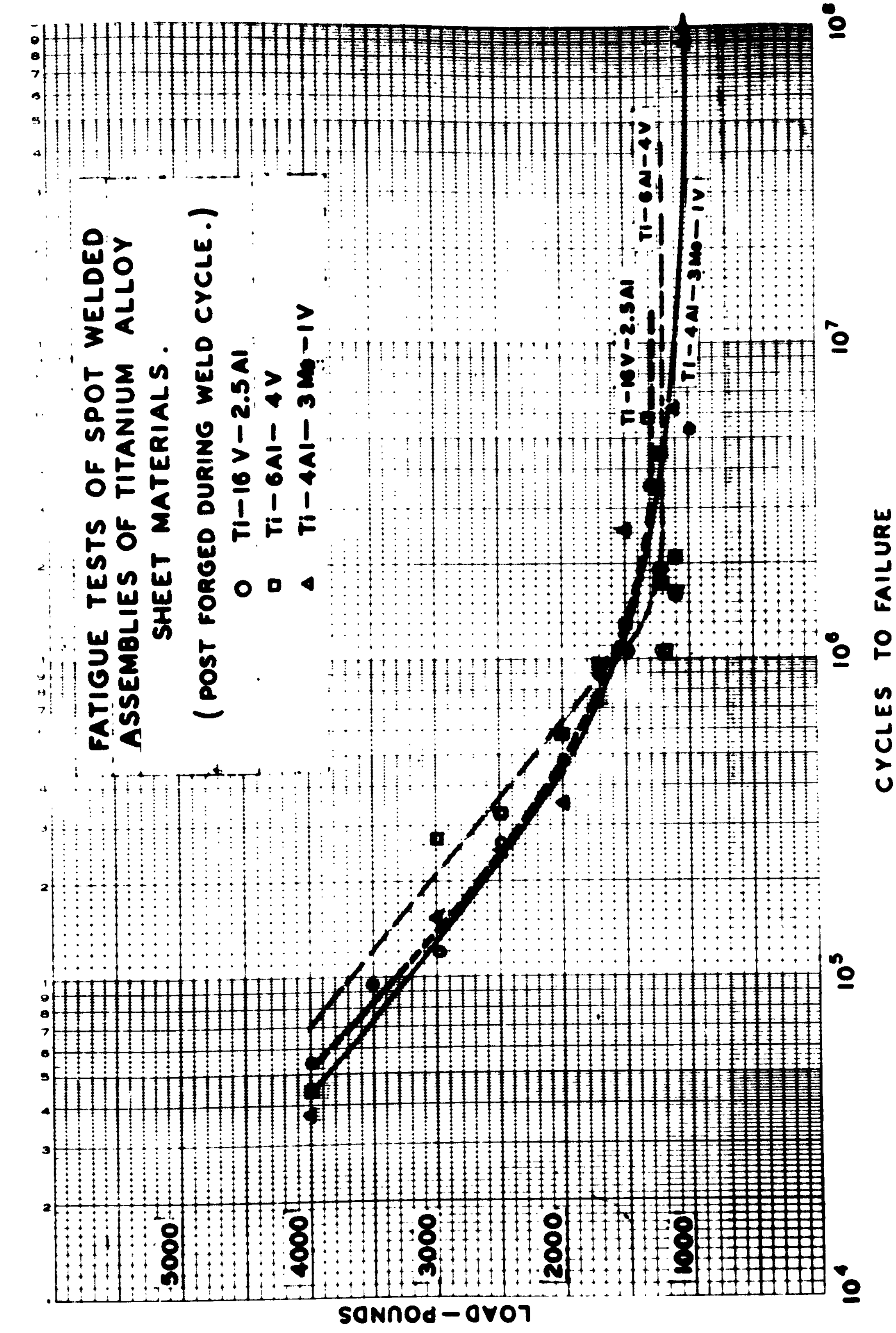
Exposure Temperature (°F)		Tensile-Shear Load at Room Temperature					
		Exposure Time					
		1 Hr.	10 Hrs.	100 Hrs.	250 Hrs.	500 Hrs.	1000 Hrs.
600°F		2060	----	2126	2128	1740	1764
		2148	----	2120	2128	1750	1764
		2116	----	2088	2062	1800	1758
	Average	2108	----	2111	2106	1763	1762
700°F		2012	1900	1820			1500
		2118	1980	1732			1400
		2078	1958	1704			1420
	Average	2073	1946	1752			1440
800°F		1811	1668	1384			1392
		1920	1718	1554			1444
		1926	1708	1372			1336
	Average	1886	1698	1437			1391
900°F		1648	1454	1244			2104
		1721	1444	1316			2032
		1782	1324	1516			1988
	Average	1717	1444	1359			2041

TABLE 7



SPOT WELD SHEAR FATIGUE SPECIMEN


FATIGUE TESTS OF SPOT WELDED ASSEMBLIES OF TITANIUM ALLOY MATERIALS.
(CONSTANT WELD PRESSURE)
o – Ti-16V-2.5Al
□ – Ti-6Al-4V
▲ – Ti-4Al-3Mo-1V
Ti-4Al-3Mo-1V
Ti-6Al-4V
Ti-16V-2.5Al
LOAD – POUNDS
CYCLES TO FAILURE
5000
4000
3000
2000
1000
10^4
10^5
10^6
10^7
10^8



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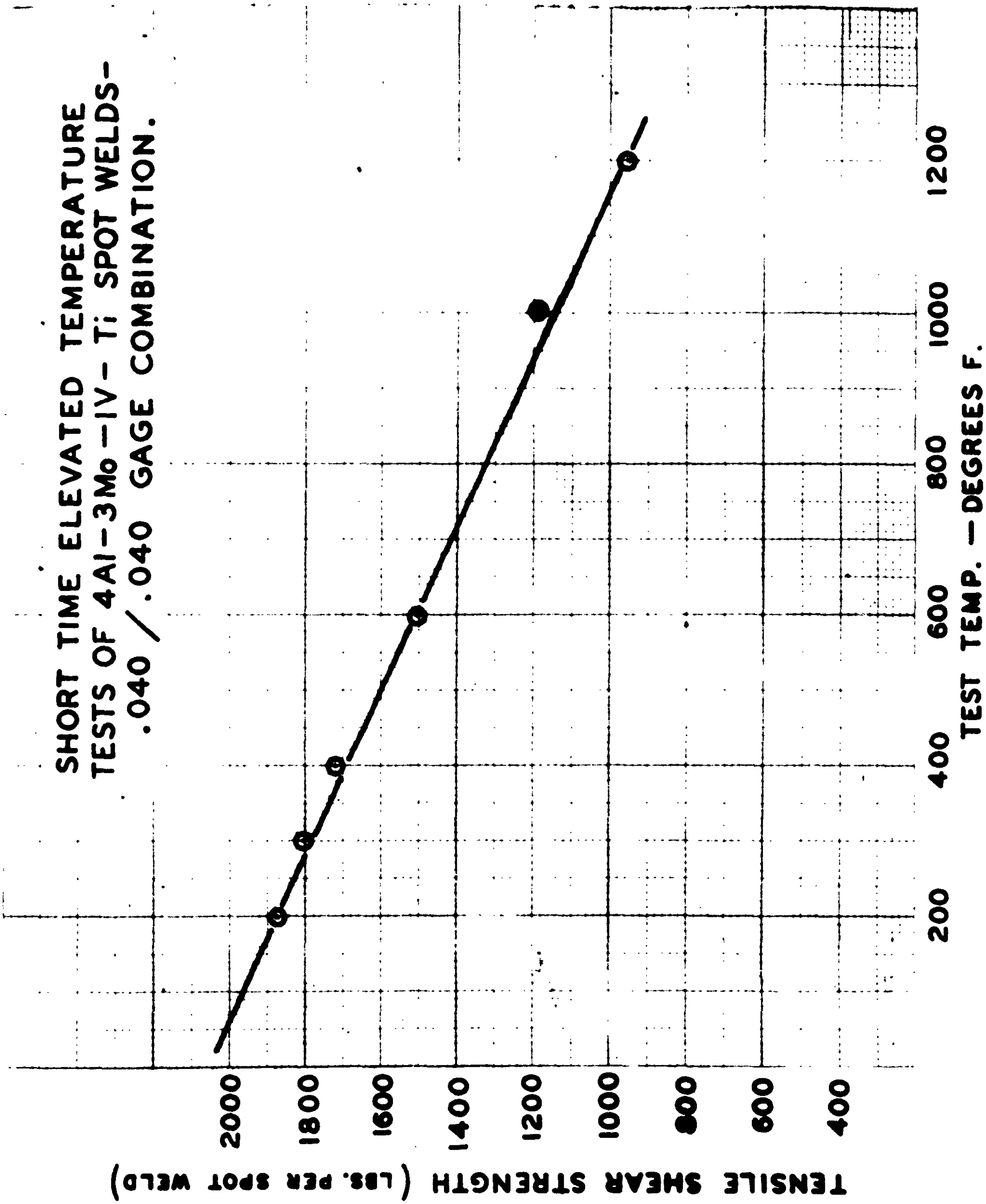
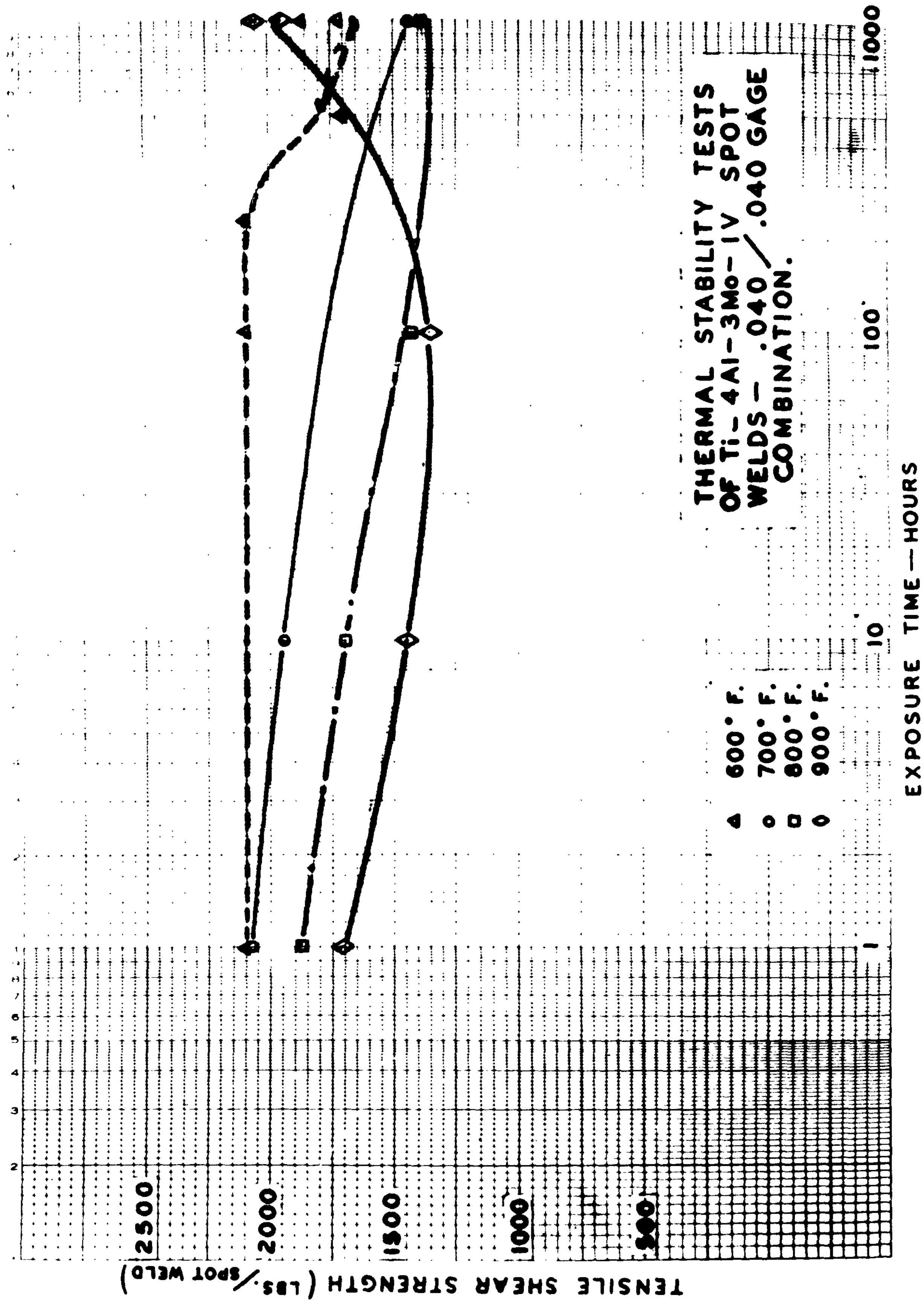

SHORT TIME ELEVATED TEMPERATURE
TESTS OF 4Al—3Mo—1V— Ti SPOT WELDS—
.040 / .040 GAGE COMBINATION.
TEST TEMP. —DEGREES F.
200
400
600
800
1000
1200
TENSILE SHEAR STRENGTH (LBS. PER SPOT WELD)
2000
1800
1600
1400
1200
1000
800
600
400



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1. Report NAMC-AML-1319
2. PAN C 10 RMA 23-1

Investigation of Spot Welding Characteristics of Titanium Alloys; by E. F. Deesing, November 1961, 18 p., 5 Plates

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ABSTRACT CARD OFFSET MARGINAL GUIDE
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